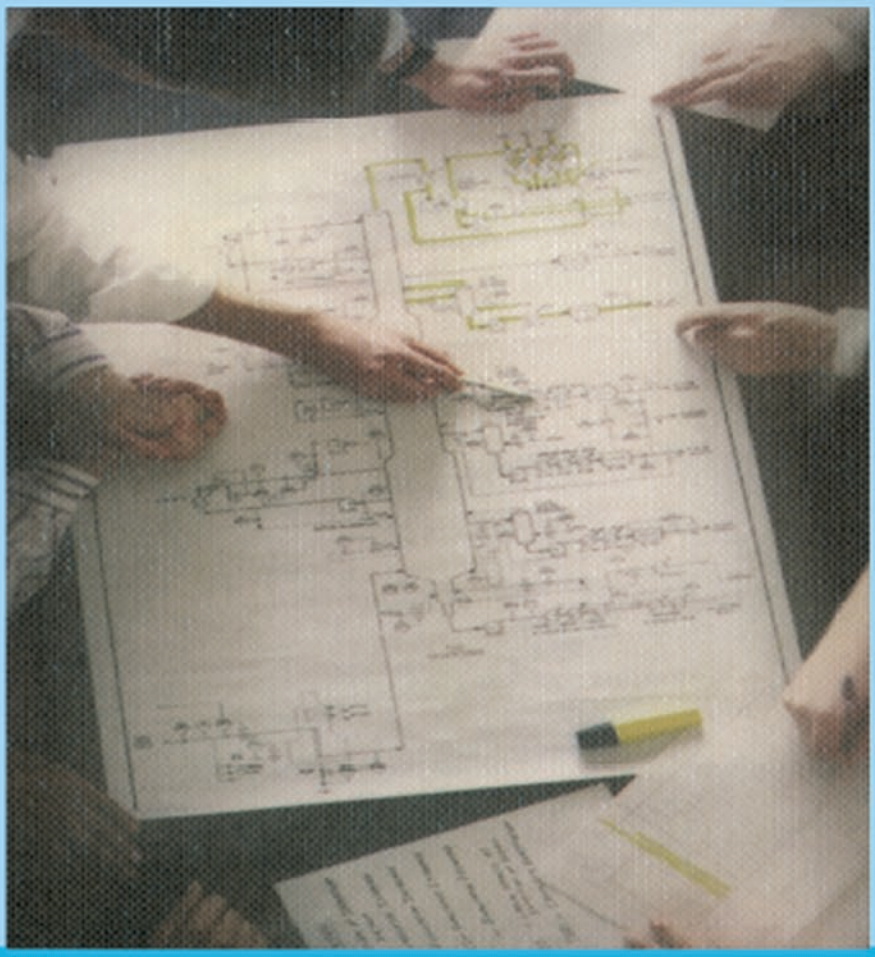
HAZOP AND HAZAN

Fourth Edition

Trevor Kletz



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Hazop and Hazan

Identifying and assessing process industry hazards

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Preface

The Institution of Chemical Engineers' example syllabus for an accredited degree in chemical engineering[1] features 'Systematic identification and quantification of hazards, including hazard and operability studies', and this book is intended to spread knowledge of these subjects.

The first edition was based on lecture notes that I had used for several years for teaching these subjects to undergraduate and graduate students, to mature students attending short courses on loss prevention and to former colleagues attending in-house courses in industry. University departments of chemical engineering may therefore find the book useful. It may also be useful for in-house courses in industry. It is intended as an introduction to the subject rather than a handbook for experts.

A few suggestions on the presentation of the material may be helpful.

Chapter 1 puts the material in context and can form an introduction to the first session of a course.

Chapter 2 deals with identification of hazards by hazard and operability studies (Hazop) and requires at least two hours. It could be presented as a lecture in one hour but it is better if those present can complete the various columns in Table 2.2 (pages 14–15), the lecturer (or discussion leader) writing them down on a board as they do so. The group must, of course, be allowed to come to different conclusions than those in the table if they wish to do so. There is no right answer. The group may consider that those who drew up Table 2.2 went too far or did not go far enough, and the group could be right.

If possible the group should not exceed 20 people; the fewer the better, as long as at least five or six are present.

Chapter 3 deals with the quantification of hazards by hazard analysis (Hazan) and requires at least three hours. Mature students seem able to take three hours at a stretch, but not undergraduates!

Chapter 4 describes some of the points to look for when reading hazard analyses carried out by others. It is intended for mature students.

Chapter 5 briefly discusses some of the objections that have been raised to Hazop and Hazan.

Chapter 6 discusses sources of data and confidence limits.

Chapter 7 gives a brief history of Hazop and Hazan.

The subjects discussed in this book and many other aspects of loss prevention are treated more extensively in F.P. Lees' *Loss Prevention in the Process Industries* (second edition, three volumes, Butterworth-Heinemann, 1996), especially Chapters 7–9 (referred to in later pages as *Lees*).

Thanks are due to the many colleagues who provided ideas for this book or commented on the draft and to the Science and Engineering Research Council for financial support for the first edition.

For the third edition I corrected a few misprints, added a few words of additional explanation here and there (especially in Sections 3.4 and 5.3 and in Chapters 6 and 7) and included some new references and some examples of accidents that could have been prevented by Hazop. In this fourth edition, about 40% longer than the third, the basic plan is unchanged. I have not added descriptions of more complex methods of calculation which might give a little more accuracy. Instead I have tried to answer more of the questions that I am often asked, tried to increase awareness of the pitfalls which await the unwary and added more examples of the applications of Hazop and Hazan. A training package on the subject of this book is available from the Institution of Chemical Engineers[2].

I have often been irritated by authors who use phrases such as, 'as discussed in an earlier chapter' without saying which one. I have therefore included cross-references whenever a topic is discussed under more than one heading.

To avoid the clumsy phrases 'he or she' and 'him or her' I have used 'he' and 'him'. Though there has been a welcome increase in the number of women employed in the process industries the manager, designer and accident victim are still usually male.

I would like to thank the many people without whose work and advice I would have been unable to write this book or prepare the successive editions.

Finally, I have tried to follow the advice of Joseph Pulitzer (1847–1911):

'Put it before them briefly so they will read it,
clearly so they will appreciate it,
picturesquely so they will remember it,
and, above all, accurately so they will be guided by its light.'

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Contents

Preface		iii
Forethoughts		xi
1	**Hazard identification and assessment**	1
1.1	Introduction	1
1.2	A note on nomenclature	5
1.3	Legal requirements	7
2	**Hazard and operability studies (Hazop)**	9
2.1	What is a Hazop?	9
2.2	Who carries out a Hazop, and what should be recorded?	20
2.3	When is a Hazop carried out and how long does it take?	26
2.4	Some points to watch during Hazop	27
2.5	An example of a Hazop	34
2.6	Could a computer carry out a Hazop?	37
2.7	The limitations of Hazop	41
2.8	'Do we need to Hazop this plant?' 'It is only a simple project' or 'It is similar to the last one'	47
2.9	The use of quantitative methods during Hazop	50
2.10	The use of Hazop in other industries	51
2.11	Other methods of identification	54
2.12	Auditing Hazop	56
2.13	Conclusion	56
Appendix to Chapter 2 – Some accidents that could have been prevented by Hazops		61
A2.1	Reverse flow	61
A2.2	Bhopal	62
A2.3	A fire in a water sump	63
A2.4	A protective device that did not work	63
A2.5	Services and modifications – two neglected areas	64
A2.6	A computer-controlled batch reaction	65

A2.7 Abbeystead – an explosion in a water pumping station 67
A2.8 The Sellafield leak 67
A2.9 Formation of separate layers 71
A2.10 The need for different sorts of knowledge 72
A2.11 An incident from another industry 75

3 Hazard analysis (Hazan) 77
3.1 Objective 77
3.2 Why do we want to apply numerical methods to safety problems? 78
3.3 The stages of Hazan 80
3.4 Choosing targets or criteria 83
3.5 Estimating how often an incident will occur 105
3.6 Pitfalls in Hazan 120
3.7 The man or woman in the middle 130
3.8 Examples of Hazan 133
3.9 A summary of the main sources of error in Hazan 143
3.10 A final note 143

Appendix to Chapter 3 – Belt and braces 148

4 A manager's guide to hazard analysis 152
4.1 Introduction 152
4.2 Arithmetic, algebra and units 153
4.3 The model 154
4.4 The unforeseen hazards 158
4.5 The assumptions 159
4.6 Data 160
4.7 Human reliability 162
4.8 The recommendations 163
4.9 Comparison with experience 164
4.10 Closed shop or open shop? 165

5 Objections to Hazop and Hazan 168
5.1 Objections to Hazop 168
5.2 Technical objections to Hazan 169
5.3 Popular objections to Hazan 181
5.4 The regulator's view 187

Appendix to Chapter 5 – Limitations on the application of quantitative methods to railway travel 193

6 Sources of data and confidence limits 195
6.1 Data banks and data books 195

6.2 If failure has never occurred 196
6.3 Confidence limits 196
6.4 Data on mechanical equipment may be data on people 197
6.5 Chaos 198
6.6 Pitfalls in extrapolating data 199

7 The history of Hazop and Hazan 203
7.1 Hazop 203
7.2 Hazan 207

Conclusions 213

Addendum 1 – An atlas of safety thinking 214

Addendum 2 – Myths of Hazop and Hazan 218

Index 224

The Author

Known throughout the process industries as a gifted communicator on safety matters, Trevor Kletz has wide knowledge of both practice and theory. He joined Imperial Chemical Industries on graduating as a chemist and spent eight years in research, sixteen in production management and the last fourteen as safety adviser to the Petrochemicals Division. On retiring from ICI he joined Loughborough University of Technology, at first full-time and then from 1986 as a Visiting Fellow. He has written nine books and more than a hundred papers on loss prevention and process safety and is a Fellow of the Royal Academy of Engineering, the Institution of Chemical Engineers, the Royal Society of Chemistry and the American Institute of Chemical Engineers.

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Critical Aspects of Safety and Loss Prevention
Butterworths
1990, ISBN 0 408 04429 2

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Forethoughts

'We Athenians in our persons take our decisions on policy and submit them to proper discussion. The worst thing is to rush into action before the consequences have been properly debated. And this is another point where we differ from other people: we are capable at the same time of taking *risks and* estimating *them beforehand. Others are brave out of ignorance; and when they stop to think they begin to fear. But the man who can most truly be accounted brave is he who best knows the meaning of what is sweet in life, and what is terrible, and then goes out undeterred to meet what is to come.'*

From Pericles' funeral oration in *Thucydides' History of the Peloponnesian Wars*, ca. 430 BC (quoted in *Probabilistic Safety Assessment and Management*, edited by P.C. Cacciabue and I.A. Papazoglu, Springer, 1996)

'... there's a tremendous gap between what can be done and what is actually done, and a great deal hinges on the quality of the personnel in any given organisation.

'Success depends on an awareness of all possible failure modes, and whenever a designer is either ignorant of, or uninterested in, or disinclined to think in terms of failure, he can inadvertently invite it.'

Ivars Peterson, *Fatal Defect*, Random House, 1996, page 111

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Hazard identification and assessment

1

'The great end of life is not knowledge but action.'
T.H. Huxley (1825–1895)

1.1 Introduction

The techniques for identifying hazards — for finding out what hazards are present in a plant or process — and the techniques for assessing those hazards — for deciding how far we ought to go in removing the hazards or protecting people from them — are often confused. Figure 1.1 may help to make the differences clear.

The left-hand side shows some of the methods used for identifying hazards — and problems that make operation difficult.

Some hazards and problems are obvious. For example, if we manufacture ethylene oxide by mixing oxygen and ethylene close to the explosive limit we do not need a special technique to tell us that if we get the proportions wrong there may be a big bang.

The traditional method of identifying hazards — in use from the dawn of technology until the present day — was to build the plant and see what happens — 'every dog is allowed one bite'. Until it bites someone, we can say that we did not know it would. This is not a bad method when the size of an incident is limited but is no longer satisfactory now that we keep dogs which

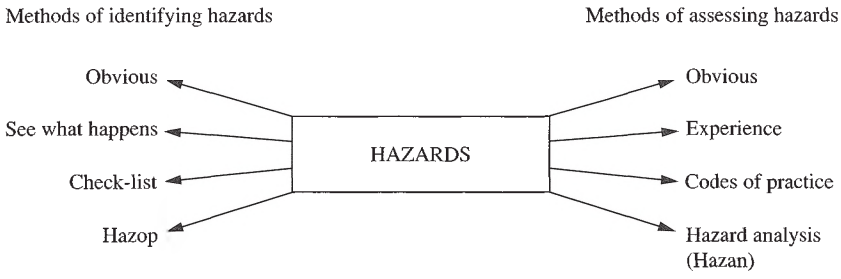

Figure 1.1 Methods of identifying and assessing hazards

may be as big as Bhopal (over 2000 killed in one bite) or even Flixborough (28 killed). We need to identify hazards before the accidents occur.

Check-lists are often used to identify hazards but their disadvantage is that items not on the list are not brought forward for consideration and our minds are closed to them. Check-lists may be satisfactory if there is little or no innovation and all the hazards have been met before, but are least satisfactory when the design is new.

For this reason the process industries have come to prefer the more creative or open-ended technique known as a hazard and operability study or Hazop. It is described in Chapter 2. It is now widely used on designs for new plants and plant extensions but, because of the effort involved, has been less widely used on existing plants.

Samuel Coleridge described history as a 'lantern on the stern', illuminating the hazards the ship has passed through rather than those that lie ahead. It is better to illuminate the hazards we have passed through than not illuminate them at all, as we may pass the same way again, but we should try to see them before we meet them. Hazop can be a lantern on the bow.

Unfortunately we do not always learn from the hazards we have passed through, but that is outside the scope of this book[1,2].

Other methods of identifying hazards are described in *Lees*, Chapter 8, and are summarized in Section 2.11, page 54.

After we have identified the hazards we have to decide how far to go in removing them or in protecting people and property. Some of the methods used are listed on the right-hand side of Figure 1.1. Sometimes there is a cheap and obvious way of removing the hazard; sometimes our experience or a code of practice tell us what to do. Sometimes it is less easy to decide. We can then try to work out the probability of an accident and the extent of the consequences and compare them with a target or criterion. This method is called hazard analysis or Hazan in this book. Sometimes a five-minute estimation is sufficient. On other occasions detailed studies can take many weeks.

Hazop can and should be applied to all new designs, unless we are making an exact copy of an existing plant which has been proved satisfactory, as we need to know all the hazards and all the problems that can prevent efficient operation. Hazan on the other hand should be used selectively — there are neither the need, the data nor the resources to attempt to quantify every problem on every plant. Carling[3] has described a Hazop which produced 326 recommendations of which only seven justified a detailed hazard analysis.

In the development of a design the Hazop comes first. We identify the hazards and the problems that prevent efficient operation and then decide what to do about them. However, if there is an obvious major hazard we may start on

Table 1.1 The differences between Hazop and Hazan

Hazop	Hazan
Identifies hazards	Assesses hazards
Preferred technique: use on every project	Selective technique: use when others fail
Qualitative	Quantitative
Done by a team	Done by one or two people
Also called: 'What if?'	Also called: Risk analysis Risk assessment Probabilistic risk assessment (PRA) Quantitative risk assessment (QRA)

the Hazan before the Hazop is carried out. In a Hazop the operability part is as important as the hazard part. In most studies more operating problems are identified than hazards.

Hazop and Hazan are often confused, and Hazop is sometimes used to describe any technique for identifying hazards. Figure 1.1 and Table 1.1 should make the difference clear. However, if someone asks you to carry out a Hazop or Hazan on a design, first make sure that the questioner is clear on the difference between them and is using the terms correctly.

The techniques described in later chapters are sophisticated techniques which enable companies to use their resources more effectively. They assume that the general level of management is competent, that the plant will be operated and maintained in the manner assumed by the design team and in accordance with good management and engineering practice. In particular they assume that protective systems will be tested regularly and repaired promptly when necessary.

If these assumptions are not true then Hazop and Hazan are a waste of time. It is no use identifying hazards or estimating their probability if no-one wants to do anything about them; it is no use installing trips and alarms if no-one is going to use or maintain them. The time spent on Hazop and Hazan would be better spent on bringing the safety consciousness of employees and management up to standard. The following is a summary of a paper by Atallah and Guzman on doing this in developing countries[4] (and perhaps elsewhere):

- Be patient when you are waiting for data, prompt when asked for advice.
- Include in your team someone who speaks the local language.

- Submit your report in draft for comment; justify your criticisms and recommendations.
- Photograph problem areas.
- Visit the plant at night.
- Wear all the required protective clothing and follow all the safety rules.
- Expect to be asked about subjects not covered in the remit.
- Provide the client with copies of references, codes, and so on, not just a list of them.
- Involve the client in your audit.
- Learn as much as you can beforehand about the customs and culture of the country, expect a cultural shock and do not discuss politics or religion.

If you wish to introduce Hazop and/or Hazan into an organization in which they have not been used before, you should start small. Do not try to set up a large team capable of studying all new and existing designs. Instead apply the methods to one or two problems. If your colleagues find that the methods are useful they will ask for more and the use of the techniques will grow. If, on the other hand, the methods do not suit your organization, little has been lost.

Despite all our efforts we shall fail to foresee every hazard and some will result in accidents. We should learn from these accidents, not only from those that result in serious injury or damage but also from those that do not — for example, leaks that do not ignite. If these 'near-misses' are not investigated and the lessons made known to those concerned, next time injury or damage may result.

In my former company, ICI, Hazop and Hazan form part of a series of six hazard studies carried out on new projects as they progress[5]. They are:

(1) Exploratory phase — identification of basic hazards and assessment of suitability of possible sites.
(2) Flowsheet phase — identification and assessment of significant hazards, using Hazan.
(3) Detailed design — Hazop.
(4) Construction — a check that decisions made in earlier studies have been implemented.
(5) Commissioning — final inspection.
(6) Post-commissioning — safety audit and review of modifications.

It seems from this list that the assessment of hazards is carried out in Study 2 before the hazards have been identified by Hazop in Study 3! However, the obvious hazards should be assessed as soon as possible. The Hazop will identify other hazards, most of which will be assessed qualitatively during the Hazop, but some of which will have to be assessed outside the meeting by Hazan.

Section 2.7 (page 41) discusses the limitations of the six-stage procedure and of Hazop in particular. It also makes it clear that assessing the probability and size of a hazard, though valuable and often necessary, is always a second-best choice. When we can we should avoid the hazard. Before we estimate the probability that a toxic or flammable substance will leak and the injury and damage that will result, we should ask if a non-flammable or non-toxic material could be used instead or if it is possible to use so little of the hazardous material that it would not matter if it all leaked out.

1.2 A note on nomenclature

Hazard analysis has several other names (see Table 1.1 on page 3). When I wrote my first paper on the use of quantitative methods of assessing risks in the chemical industry[6] I started by using the term 'risk analysis'. Then I realized that ICI had sponsored a book entitled *Risk Analysis*[7] which described methods of assessing the commercial risks of a project. I therefore introduced the term 'hazard analysis' instead, but other writers often use 'risk analysis'.

In an attempt to standardize nomenclature the Institution of Chemical Engineers has published a guide[8]. It suggests that 'hazard analysis' is used to describe methods of identifying hazards and estimating the probability and consequences of an incident but that it should exclude the crucial final step of deciding what should be done about them (see Chapter 3). The book suggests that what I call hazard analysis (or Hazan) should be called 'risk assessment'.

Many writers, particularly in the US, call it 'quantified (or quantitative) risk assessment' (QRA) or 'probabilistic risk assessment' (PRA) and the former term is now used by the UK Health and Safety Executive[9].

I have nevertheless continued to use 'hazard analysis' in the same sense as I used it in the first edition of this book because the term is still widely used with this meaning, especially in the chemical industry, and because its contraction, Hazan, contrasts conveniently with Hazop. (*Hazop and Risk Assessment* would not be a good title for this book.) Figure 1.2 (page 6) summarizes the different ways in which the various terms are used.

The following are some of the other terms used:

- A *hazard* is a substance, object or situation that can give rise to injury or damage.
- A *risk* is the likelihood that an accident or damage of a particular type and severity will occur in a particular period of time or as the result of a particular action or event. It may be expressed as a frequency (the number of occurrences per year or other period of time) or as the probability that it will occur following a particular action or event. For example, if I never carry an

umbrella I estimate that I will get wet 20 times/year; if I go out today without an umbrella I estimate that the probability that I will get wet is 0.3 (30%). Risk is thus a measure of the likelihood of specific consequences.

A hazard may be serious but the risk from it may be small. For example, experience over many years shows that in the UK, on average, less than one person per year has been killed by the transport of flammable chemicals. The risk of being killed in this way is therefore small, less than 1 in 60 million per person per year, though the hazard, the potential for damage and injury, is large.

Figure 1.3 shows the definition of risk adopted by the European Community for use in risk assessment[10].

- The *consequences* of a hazard may be *immediate* or *long-term*. Thus fires and explosions and some toxic chemicals such as chlorine produce immediate injuries. Other chemicals such as asbestos produce ill effects only after many years have passed. Ultraviolet radiation produces both immediate effects (sunburn) and long-term effects (skin cancer).
- Some consequences are *deterministic* (that is, they always follow exposure) while others are *probabilistic* (that is, they may or may not follow). For example, if an object is dropped from the top of a structure it will always fall to the ground (deterministic) but the effects are probabilistic. It may kill someone, may cause serious injury, may cause slight injury or may merely

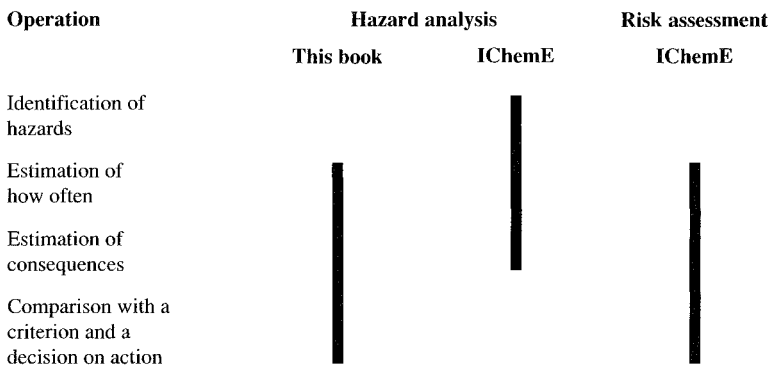

Figure 1.2 Some definitions compared
Quantified risk assessment (QRA) and probabilistic risk assessment (PRA) are usually synonyms for 'hazard analysis', as used in this book, but the terms may be widened to include the identification of hazards

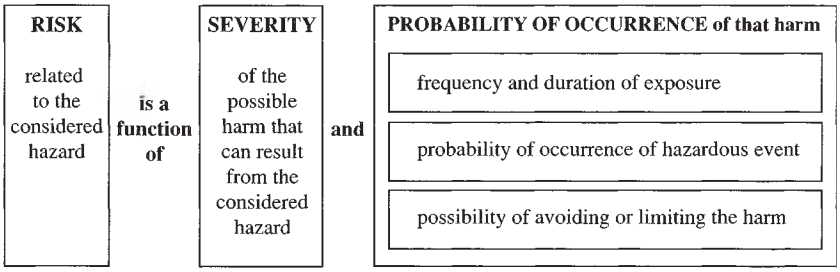
RISK
related to the considered hazard
is a function of
SEVERITY
of the possible harm that can result from the considered hazard
and
PROBABILITY OF OCCURRENCE of that harm
frequency and duration of exposure
probability of occurrence of hazardous event
possibility of avoiding or limiting the harm

Figure 1.3 The European Community's definition of risk

cause damage. In the same way, exposure to high concentrations of certain chemicals will always cause injury (though the precise degree of injury will vary). Exposure to low levels may result in cancer, the extent of the exposure determining the probability of contracting the disease rather than its severity.

The aim of this book is to help readers manage probabilistic events.

1.3 Legal requirements

In the UK the law requires all employers to carry out a five-step risk assessment[11,12]:

(1) Look for the hazards.
(2) Decide who might be harmed and how.
(3) Evaluate the risks.
(4) Record the findings.
(5) Review the assessment from time to time.

In many cases a simple walk round followed by a consideration of the findings may be sufficient for steps (1)–(3) but in other cases a Hazop, perhaps followed by a Hazan, may be necessary. Special regulations apply to major hazards and to offshore installations and a formal hazard identification followed by a quantitative assessment of the risks may be required. Many other countries have similar requirements.

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Hazard and operability studies (Hazop)

2

'Since the destruction of the Temple, the gift of prophecy has been denied to prophets and bestowed upon scholars.'
Rabbi Eudemus of Haifa

'There is a way of going about one's work in chemical engineering more certain and less expensive than the time-honoured process of trial and error.'
George E. Davis[34]

2.1 What is a Hazop?

As I explained in Chapter 1, a hazard and operability study is the method recommended for identifying hazards and problems which prevent efficient operation. In what follows the technique is described as it would be applied to a continuous plant. Modifications of the technique, so that it can be applied to batch plants, are described only briefly (in Section 2.1.1, page 16). References 1 and 2 give more detail.

Hazop is a technique which provides opportunities for people to let their imaginations go free and think of all possible ways in which hazards or operating problems might arise, but — to reduce the chance that something is missed — it is done in a systematic way, and each pipeline and each sort of hazard is considered in turn. The study is carried out by a team so that the members can stimulate each other and build upon each other's ideas.

A pipeline for this purpose is one joining two main plant items — for example, we might start with the line leading from the feed tank through the feed pump to the first feed heater. A series of guide words are applied to this line in turn. The words are:

NONE	PART OF
MORE OF	MORE THAN (or AS WELL AS)
LESS OF	OTHER THAN

NONE, for example, means no forward flow or reverse flow when there should be forward flow. We ask:

- Could there be no flow?
- If so, how could it arise?
- What are the consequences of no flow?
- Are the consequences hazardous or do they prevent efficient operation?
- If so, can we prevent no flow (or protect against the consequences) by changing the design or method of operation?
- If so, does the size of the hazard or problem (that is, the severity of the consequences multiplied by the probability of occurrence) justify the extra expense?

The same questions are then applied to 'reverse flow' and we then move on to the next guide word, MORE OF. Could there be 'more flow' than design? If so, how could it arise? And so on. The same questions are asked about 'more pressure' and 'more temperature' and, if they are important, about other parameters such as 'more radioactivity' or 'more viscosity'. Table 2.1 summarizes the meanings of the guide words while Figure 2.1 summarizes the whole process.

Table 2.1 Deviations generated by each guide word

Guide word	Deviations
NONE	No forward flow when there should be — ie, no flow or reverse flow
MORE OF	More of any relevant physical property than there should be — eg, higher flow (rate or total quantity), higher temperature, higher pressure, higher viscosity, etc
LESS OF	Less of any relevant physical property than there should be — eg, lower flow (rate or total quantity), lower temperature, lower pressure, etc
PART OF	Composition of system different from what it should be — eg, change in ratio of components, component missing, etc
MORE THAN	More components present in the system than there should be — eg, extra phase present (vapour, solid), impurities (air, water, acids, corrosion products), etc
OTHER THAN	What else can happen apart from normal operation — eg, start-up, shutdown, uprating, low rate running, alternative operation mode, failure of plant services, maintenance, catalyst change, etc